

# COMPARISON OF BEAM SIZES AT THE COLLIMATOR LOCATIONS FROM MEASURED OPTICS AND BEAM-BASED COLLIMATOR ALIGNMENT AT THE LHC

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## Abstract

At the Large Hadron Collider (LHC), the collimation hierarchy is defined in units of the betatron beam size using the sizes at each collimator location. The beam size at a given collimator can be inferred from the gap measurement during beam-based alignment campaigns, when the collimator touches a reference beam halo defined with the primary collimators. On the other hand, the beta functions at each collimator are also measured as a part of the standard LHC optics validation. This paper presents a comparison of the beam size measurements at the collimator locations applying these two techniques for different machine configurations. This work aims at determining which is the most reliable method for setting the collimator gaps at the LHC.

## INTRODUCTION

The LHC accelerates two counter-rotating beams to a nominal energy of 7 TeV, corresponding to 362 MJ of stored energy per beam. An uncontrolled beam loss of only  $7.6 \times 10^6 \text{ p s}^{-1} \text{ m}^{-1}$  in a superconducting magnet can induce enough heating to cause a quench. In Run 1, a multi-stage system composed of 43 collimators per beam was operated to protect the LHC against losses of circulating beam [1]. Each collimator is composed of two jaws which need to be positioned equidistant from the beam, based on the beam centre and beam size at the collimator location. The upstream and downstream corners of each jaw can be moved independently by dedicated stepper motors. Most of the LHC collimators are located in Insertion Region (IR) 3 and IR 7 to clean particles with large momentum and betatron offsets, respectively. The IR7 horizontal aperture is shown in Fig. 1. The collimators are installed in the horizontal, vertical and skew planes to ensure the best coverage of the transverse phase space.

## COLLIMATOR ALIGNMENT

The beam center and the beam size at each collimator are measured during a commissioning period at the start of the run. These values are measured for four machine modes: injection, flat top, squeezed separated, and colliding beams, and are used to calculate the operational jaw settings for the whole run. Thanks to the reproducibility of the beam orbit, one set up per machine mode per year has proven to be

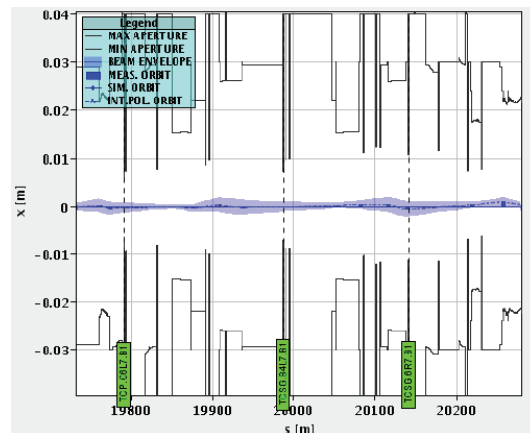


Figure 1: The IR7 horizontal aperture and beam orbit, with the envelope denoting the 1- $\sigma$  beam size. The green text boxes show names of a few IR7 horizontal collimators.

sufficient for now. Alignments are repeated if the machine configuration (e.g.  $\beta^*$ , crossing angle) is changed.

Each collimator is set up using a four-step procedure [2]. The jaw of a reference collimator, taken to be the IR7 primary collimator (TCP) in the same plane as the collimator to be aligned, is first moved in steps of  $5 \mu\text{m}$  (top energy) or  $20 \mu\text{m}$  (injection energy). A feedback loop is used to stop the movement when the beam losses from a downstream Beam Loss Monitor (BLM) exceed a pre-defined threshold [3] (step 1). The opposite jaw is then aligned to the beam. After the reference cut in the halo is established, the  $i^{\text{th}}$  collimator  $i$  can be aligned (step 2). The reference collimator is re-aligned to the beam to account for halo depletion during the previous alignment (step 3). Finally, the collimator is retracted to the hierarchy positions (step 4).

At the start of the horizontal collimator alignment, the momentum halo is cut using the primary collimator in the high-dispersion region in IR3. This ensures that the halo intercepted by the other collimators is dominated by the betatron contribution, and has proved to give more stable and reliable results [6] for the beam centres. The inferred beam size at the collimator  $i$  is expressed in terms of the jaw half gap and the reference cut in units of  $\sigma$ ,  $n_1$ :

$$\sigma_i^{\text{inf}} = \frac{x_i^L - x_i^R}{n_1^{k-1} + n_1^k} \quad (1)$$

where  $x_i^L$  and  $x_i^R$  are the left and right aligned jaw positions, and  $k$  is an index for the number of reference collimator alignments. The half-gap opening  $n_1$  in units of  $\sigma$  for the two reference collimator alignments is calculated

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the  $\beta$ -function by considering systematic and statistical errors as well as correlations. In our case 10 BPM combinations within a range of 11 BPMs have been used per probed BPM. The measured optical functions at the BPM positions are then propagated to other elements, such as the collimators, via MADX [5].

## RESULTS COMPARISON

$$\sigma_i^{nom} = \sqrt{(\beta_{x,i}\epsilon_x + (D_i\delta_p)^2)\cos^2\psi_i + \beta_{y,i}\epsilon_y\sin^2\psi_i} \quad (4)$$

where  $\psi_i$  is the azimuthal angle of the collimator,  $\epsilon$  is the geometrical beam emittance,  $D_i$  is the dispersion function and  $\delta p$  is the r.m.s. energy spread. Vertical dispersion is neglected. The comparison of the measured to nominal beam size ratios calculated from the alignment of collimators in low-dispersion regions and the measured optics, as well as the calculated and measured  $\beta$ -functions at injection and flat top is shown for B1 in Fig. 2. Similar results were obtained for B2 collimators. The skew collimators were neglected from the analysis due to further errors introduced

## 1: Circular and Linear Colliders

## T19 - Collimation



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